Space Technology Division

Updated TPS Requirements for Missions to Titan

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Outline

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  - Candidate TPS Materials
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- Huygens Support
  - UV Materials Testing
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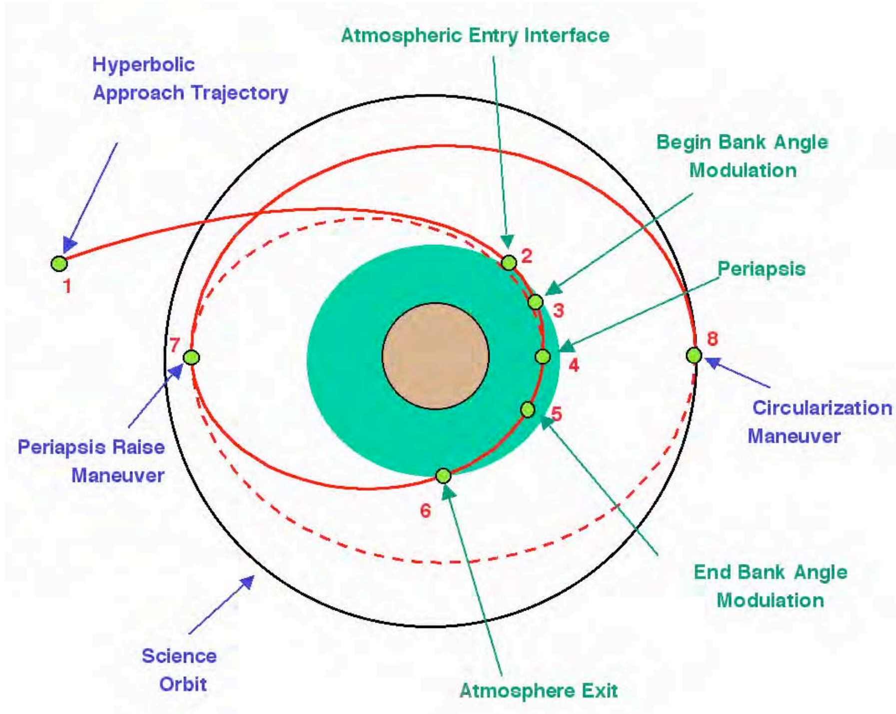
- Updated Aerocapture Analysis
  - Revised Stagnation Point Heating
  - Revised Stagnation Point TPS Requirements
- Summary and Conclusions

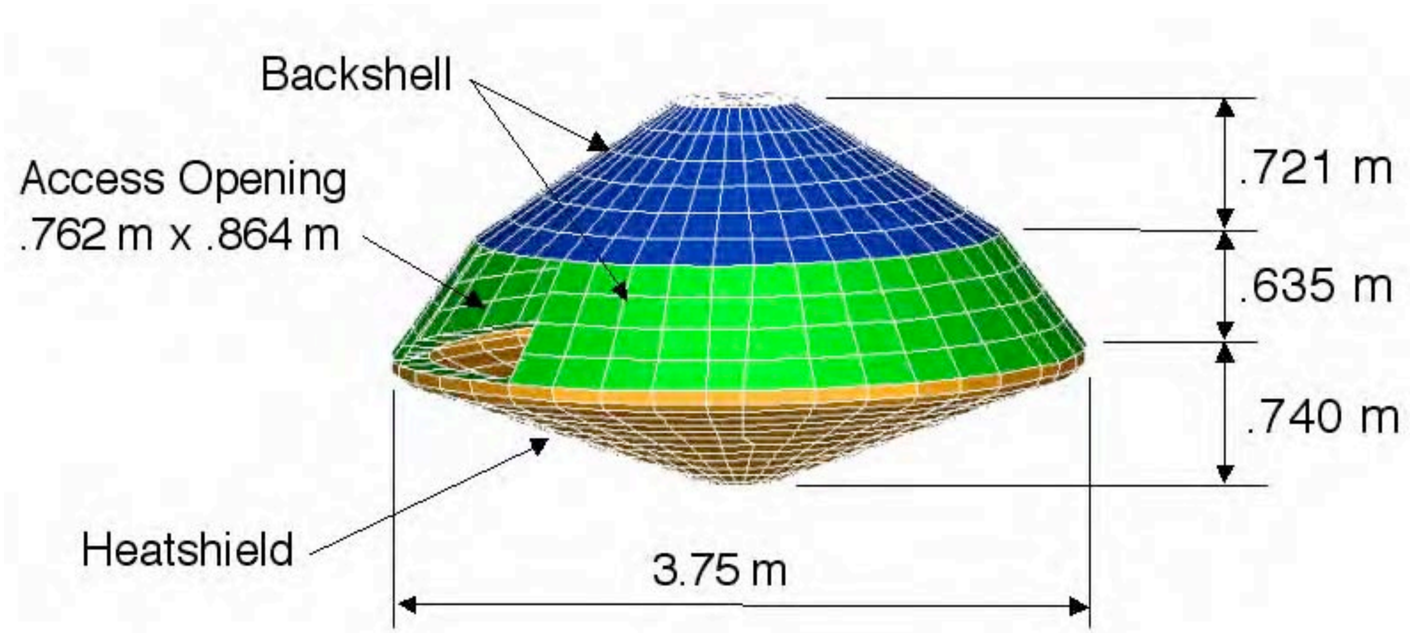
Background

- NASA Systems Analysis Study for Titan aerocapture mission conducted in 2002
  - Discipline experts from several NASA centers
- 590 kg orbiter delivered to Titan
  - Earth Gravity Assist (EGA)
  - Solar Electric Propulsion (SEP)
  - 5.9 years trip time
  - V_e (inertial) ≈ 6.5 km/s (1000 km)
- Rigid aeroshell
  - Flying at angle-of-attack
  - Lift vector control via bank modulation (only)



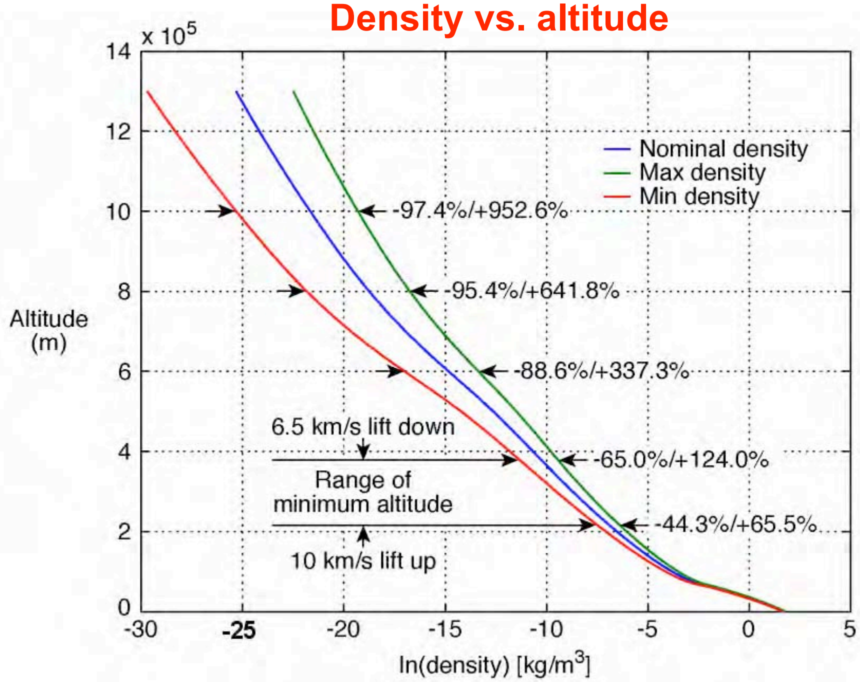
Background - aeroshell configuration

- 70° half-angle blunt cone; D_{max} = 3.75 m
- L/D = 0.25
- M/C_DA = 90 kg/m^2

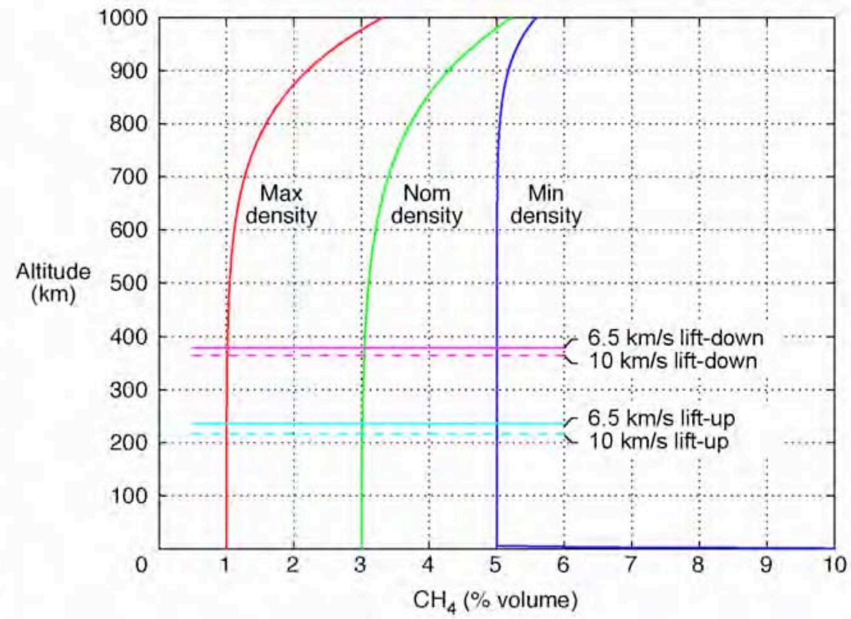


Background - Titan atmosphere

Density vs. altitude

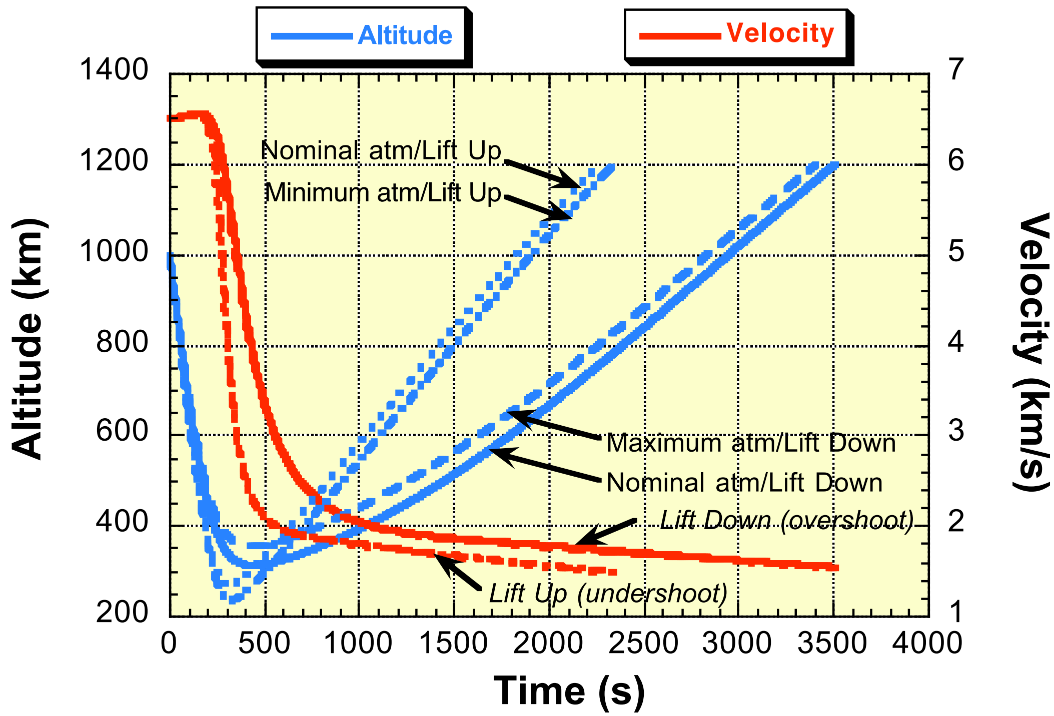


Methane concentration vs. altitude



- Composition: primarily N_2 with some Ar and CH_4
- Uncertainty in argon and methane concentrations → uncertainties in density distribution
- Yelle engineering models adopted for analysis (Justus and Duvall)
  - TitanGRAM

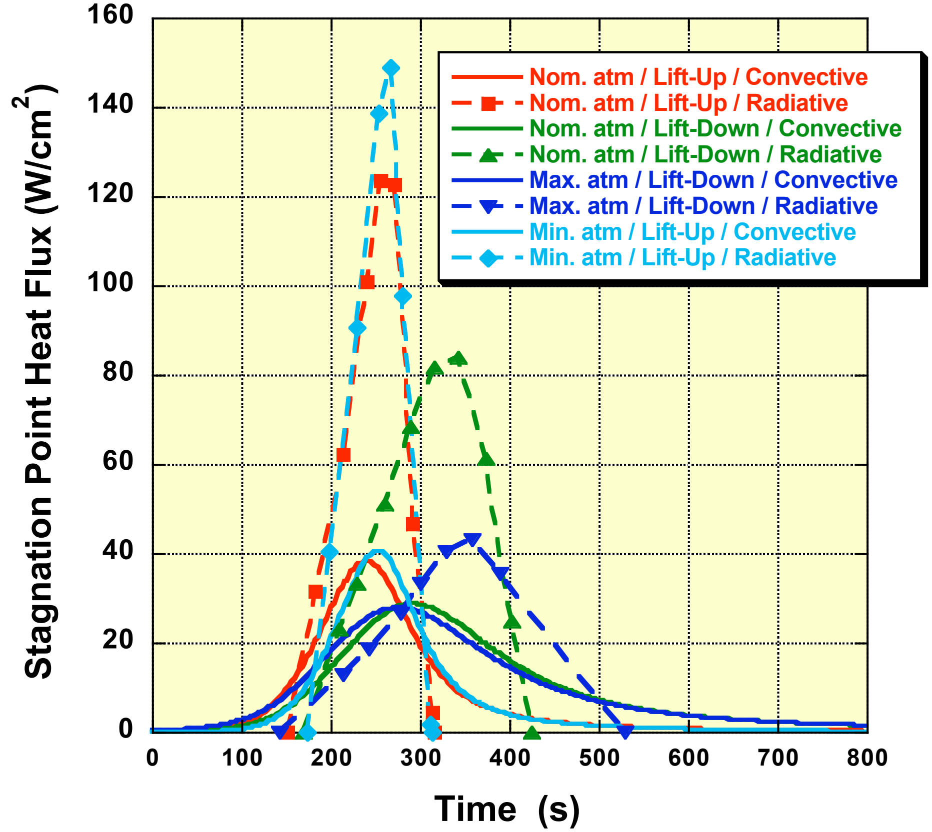
Background - aerocapture flight trajectories



- Trajectories (Way, Powell et al.) defined for range of atmospheric density models
- Lift vector control through bank modulation
- Limiting trajectories: undershoot (lift up) and overshoot (lift down)

Background - stagnation point heating

- Convective heating calculated with DPLR[1] and LAURA
- Non-equilibrium radiation with NEQAIR[2] and RADICAL
- Undershoot trajectories → largest heating *rates*
- Overshoot trajectories → largest heat *loads*
- Convective heating relatively insensitive to methane concentration
- Radiative heating proportional to methane concentration
  - Due to CN formed in the shock layer



1. Wright, M.J., G.V. Candler, and D. Bose, "*Data-Parallel Line Relaxation Method for the Navier-Stokes Equations*," AIAA Journal, Vol. 36, No. 9, pp. 1603-1609, Sep. 1998.
2. Whiting, E.E., Park, C., Liu, Y., Arnold, J.O., and Paterson, J.A., "*NEQAIR96, Nonequilibrium and Equilibrium Radiative Transport and Spectra Program: User's Manual,*" NASA RP-1389, Dec. 1996

Background - stagnation point heat load

Atmosphere model/ aerocapture trajectory	Convective heat load (J/cm^2)	Radiative heat load (J/cm^2)
Minimum atm / Lift up	5,200	15,769
Nominal atm / Lift up	5,500	10,021
Nominal atm / Lift down	7,500	12,090
Maximum atm / Lift down	7,700	8,393

- Convective heat load larger for overshoot (lift down) trajectories
  - Longer flight trajectory
- Radiative heat load varies with methane concentration in the atmosphere
- Radiative heat load (for same atmospheric model) larger for overshoot (lift down) trajectories
  - Longer flight trajectory

Background - candidate TPS materials

Material	Density (g/cm^3)	Description
Shuttle tiles (NASA)	0.192-0.352	Low-density glass-based ceramic tile with glass-based coating
SLA-561V (LMA)	0.256	Low-density cork silicone composite in Flexcore honeycomb (forebody TPS on Mars Viking, Mars Pathfinder and Mars Exploration Rover landers)
SRAM14 (ARA)	0.224	Low-density cork silicone composite fabricated with strip-collar bonding technique
SRAM17 (ARA)	0.272	Low-density cork silicone composite fabricated with strip-collar bonding technique
SRAM20 (ARA)	0.320	Low-moderate density cork silicone composite fabricated with strip-collar bonding technique
SIRCA (NASA)	0.192-0.352	Low-density ceramic tile impregnated with silicone resin
PICA (NASA)	0.256	Low-density carbon fiberform partially filled with phenolic resin (forebody TPS on Stardust spacecraft)
PhenCarb20 (ARA)	0.320	Low-moderate density phenolic composite fabricated with strip-collar bonding technique
Acusil I (ITT)	0.480	Moderate density filled silicone in Flexcore honeycomb
TUFROC (NASA)	Varies with layer sizing	Multilayer composite: carbon fiberform/AETB tile with high temperature, high emissivity surface treatment
Genesis Concept (LMA)	Varies with layer sizing	Carbon-carbon facesheet over carbon fiberform insulator (forebody TPS on Genesis spacecraft)
Carbon phenolic	1.45	Fully dense tape-wrapped or chopped molded heritage material (forebody TPS on Galileo and Pioneer Venus entry probes)

Background - TPS mass estimates *

	Maximum atmosphere - Lift Down Convective Heat Load = 7,700 J/cm² Radiative Heat Load = 8,393 J/cm²		Nominal atmosphere – Lift Down Convective Heat Load = 7,500 J/cm² Radiative Heat Load = 12,090 J/cm²	
Candidate TPS Material	Thickness (cm)	Areal weight (g/cm²)	Thickness (cm)	Areal weight (g/cm²)
SLA-561V	2.44	0.626	2.43	0.622
SRAM 14	1.57	0.353	1.55	0.348
SRAM 17	1.93	0.526	1.93	0.526
SRAM 20	2.08	0.667	2.08	0.667
PhenCarb-20	2.29	0.696	2.34	0.711
TUFROC	4.88	1.117	5.13	1.181
PICA	5.94	1.591	5.82	1.557
Genesis	---	---	5.51	1.298
Carbon phenolic	8.70	13.084	8.76	13.167

- Lift down (overshoot) trajectories are worst-case from standpoint of TPS thickness requirements
- Assumed all materials are opaque for these analyses
- Low density composites provide the lightest TPS solution (unless surface recession for undershoot trajectories leads to *unacceptable* shape change)

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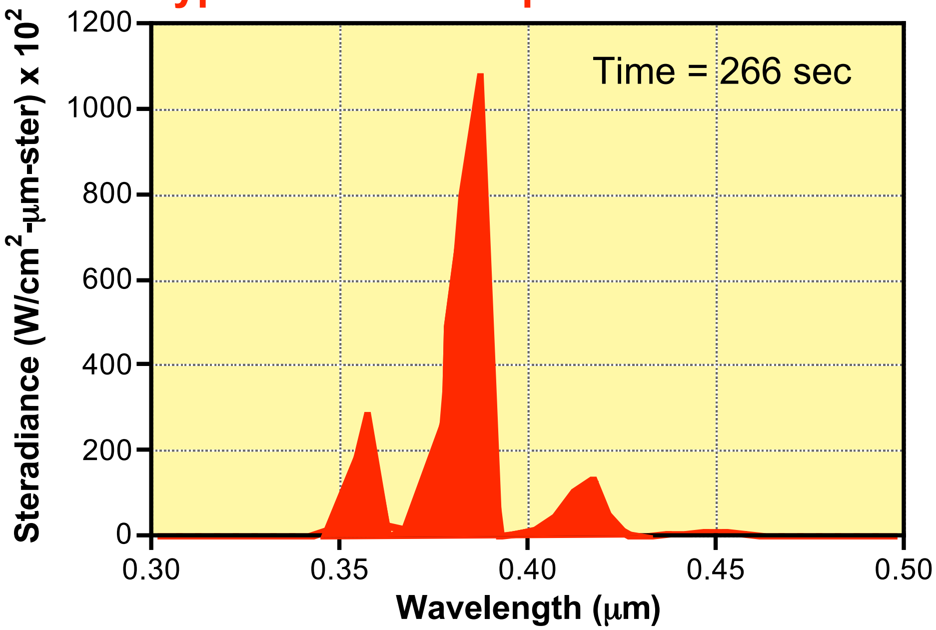
*Zero margin thicknesses based on nominal stag point heating

Background - TPS performance uncertainties

- CN radiation in a narrow band in the UV with peak at 3800 Å
- Interaction of CN radiation with low-density, porous TPS materials was of concern
  - Laser studies (80s) demonstrated degradation in material performance at shorter wavelengths (larger absorption length)
  - Potential in-depth absorption ⇒ spallation could significantly degrade material performance

Typical radiation spectrum from CN



- Due to these uncertainties, a TPS material known to be opaque at these wavelengths (TUFROC) was selected as the baseline forebody TPS for the systems analysis study (at a significant mass penalty)

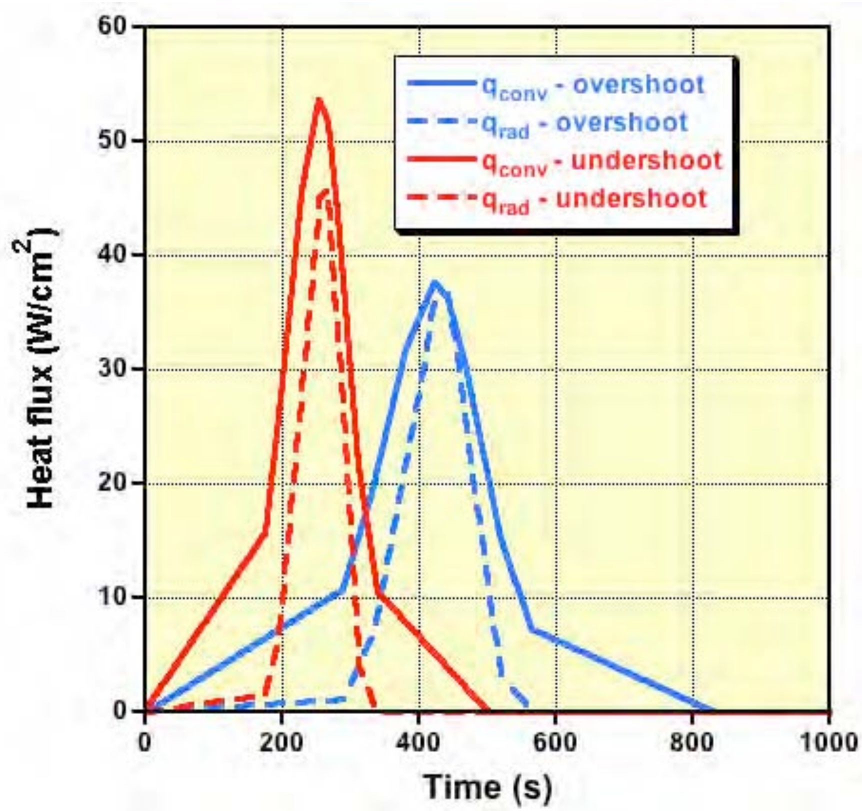
Huygens Support

- Huygens Delta Flight Acceptance Review (Cannes, Feb. 2004)
  - NASA Ames offered to test AQ60 (Huygens forebody TPS material) at UV wavelengths and relevant heat fluxes
    - Ames was in-process of acquiring a mercury-xenon lamp for such purposes under In-Space Propulsion program sponsorship
    - ESA accepted the offer and Alcatel/EADS provided samples
    - Tests demonstrated that *none* of the low-density TPS material candidates absorbed UV radiation below the surface
  - NASA radiative heating predictions for Huygens entry significantly different than what ESA employed for TPS design
    - ESA/NASA collaboration on radiation modeling
    - Agreement on the best models in Nov. 2004
    - NASA Ames shock tube data (EAST) demonstrated that actual radiative heating rates much lower than predicted by any of the models (Jan. 2005)

Updated aerocapture analysis

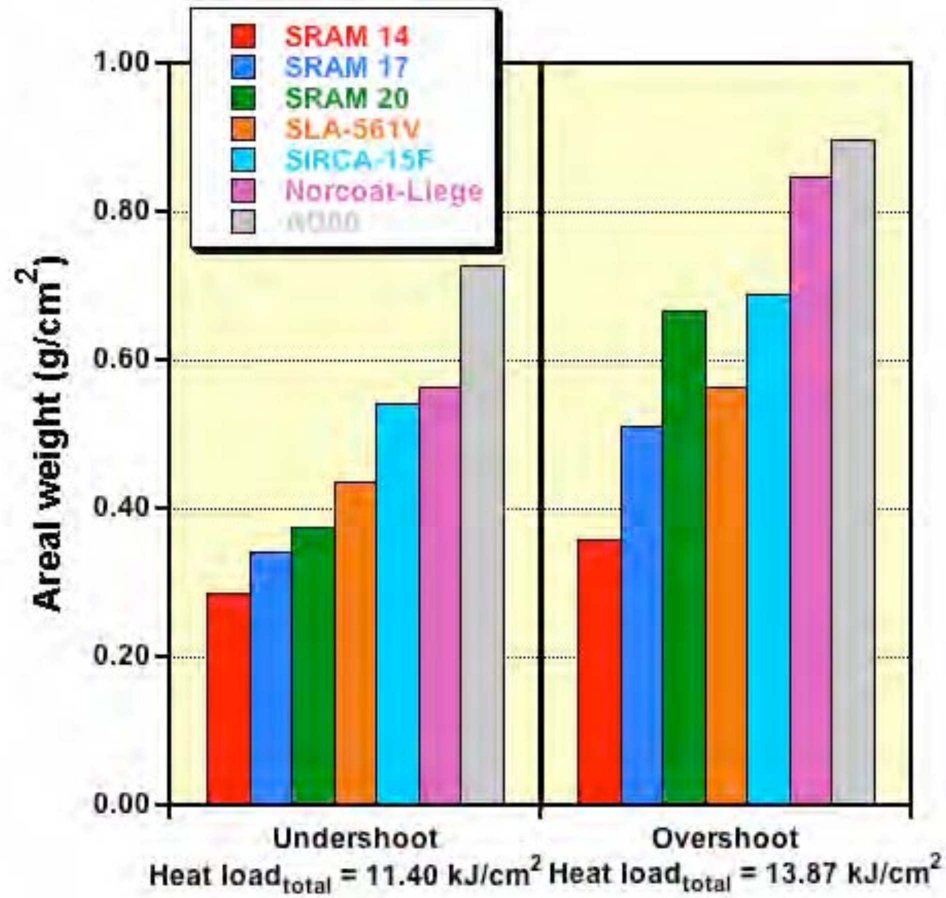
- Revised stag point heating
  - Considered same trajectories as 2002 systems analysis study
  - Minimum density (maximum CH_4) atmosphere only
  - Wright estimated radiative heating based on EAST shock tube data
  - Significant uncertainties in heating still persist
  - Wright recommended adding 30% margin to convective heating and 200% margin on radiative heating

CBE w/margins



Updated aerocapture analysis

- Revised stag point TPS requirements
  - Based on UV tests of TPS materials, low-density ablators primary candidates
  - Re-evaluated TPS thickness requirements using updated heating estimates
    - Same substructure, initial conditions, etc.
    - Added EADS' AQ60 and Norcoat-Liege to material candidates



Summary and conclusions

- Uncertainties about in-depth absorption of UV radiation resolved with mercury-xenon lamp tests
  - Low-density ablators viable candidates for Titan aerocapture and/or entry
- EAST shock tube tests demonstrated that CN radiation in Titan atmosphere is significantly lower than previous estimates
- TPS requirements for Titan aerocapture re-evaluated using updated estimates of heating
  - Low density ablators are most attractive candidates but areal weight requirements only slightly lower than results from 2002 systems analysis study despite much lower radiative heating rates
    - Ablators are more efficient at higher heating rates where ablation consumes energy
  - Use of low-density ablators provides *significant* mass savings
    - 73-98 kg in comparison to baseline TPS in 2002 systems analysis study